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SPECTRAL LINE SELECTION OF CARBON MONOXIDE LASERS

D. K. Rice

Northrop Research and Technology Center

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Northrop Research and Technology Center
High Power Laser Program Office
3401 West Broadway
Hawthorne, California 90250

Telephone: (213) 675-4611, Ext. 2821

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An intracavity water vapor cell was used to perform spectral line selection of carbon monoxide lasers. The technique was demonstrated with a low pressure longitudinal discharge laser operating in the cw and repetitive Q-switched modes and with an electron beam stabilized pulsed laser. The cell containing an appropriate amount of water vapor limited laser action in a vibrational band to those rotational lines having predicted high atmospheric transmittance.

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I. INTRODUCTION

Some of the emission lines of the CO laser are predicted to have high atmospheric transmittance.[1-6] The use of an intracavity water vapor cell to permit laser action only on these spectral lines has been experimentally demonstrated.[7,8] In order to optimize this approach the monochromatic absorptive losses introduced by such an intracavity vapor cell were measured as a function of water vapor density and additive broadening gases for 20 CO laser lines.[2, 9-11]

The objective of the investigation reported here was to verify the water vapor cell spectral line selection technique with a low pressure-longitudinal discharge carbon monoxide laser operating either cw or Q-switched. An additional objective was the demonstration of the line selection technique with an electron beam stabilized pulsed CO laser. The results show that the use of an intracavity water vapor cell is a viable technique for controlling the rotational spectral lines emitted from a carbon monoxide laser.

II. EXPERIMENT

A. Low Pressure Longitudinal Discharge Device

The basic experimental configuration for spectral line selection of a low pressure longitudinal discharge CO laser is illustrated in Fig. 1. The low pressure CO gain medium utilized a 160 cm axial discharge, liquid nitrogen-cooled, double wall Pyrex tube with calcium fluoride Brewster windows. The construction of the vapor cell was detailed previously.[2,11] For these experiments the cell temperature was maintained at 150°C while the water vapor content was varied from 0 to 700 Torr. No additive broadening gases were used during this set of experiments. As discussed in References 2 and 11, increasing the water vapor content is more effective because of the increase in the effective absorber thickness as well as the self-broadening effect. The consequences of addition nitrogen or carbon dioxide on the absorption losses of the individual CO laser lines were

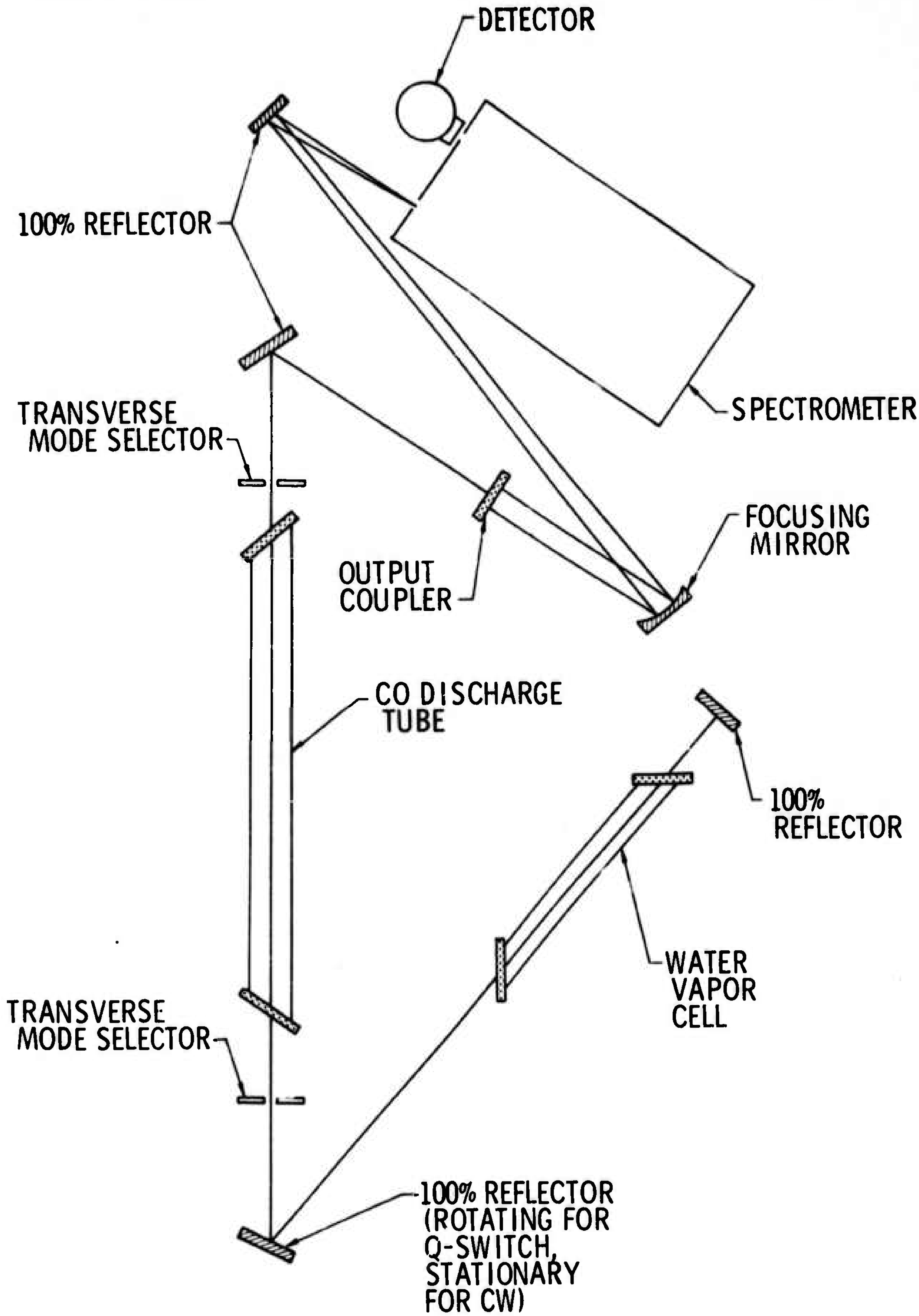

Fig. 1. Spectral Line Selection Configuration for Low Pressure Longitudinal Discharge CO Laser.

discussed in these references. As seen in Fig. 1 the output of the laser is focused into a 1.0 m, f/8.7 Czerney Turner mounting spectrometer (Jarrell-Ash Model No. 78-466). The mirror system for collecting and focusing the output beam had the same f-number as the spectrometer. A liquid nitrogen cooled In:Sb detector (Cryogenics Associates) was used at the output of the spectrometer. The output of the detector was processed using a boxcar integrator (PAR Model 160) and the spectra were recorded using a strip chart recorder (Hewlett Packard 7101B). For signal processing purposes, the output for the cw configuration was modulated with a mechanical chopper.

The effect of the line selection technique on both Q-switched and cw operation was investigated. The output spectrum of the Q-switched oscillator with no water vapor in the cell is shown in Fig. 2; the intensities of the spectral lines are relative to each other. Note that in order to generate the low vibrational band lines, the partial pressure of CO required is very low. In addition, the discharge current is low compared to normal 10 mA operating conditions. The low vibrational bands (6-5 and below) are desired because of the high atmospheric transmittance predicted for some of their rotational lines. The rotational cross relaxation of the medium is slow relative to the Q-switched pulsed width (~3 μsec) because of the low operating pressure; this fact, as well as the increased gain per line with Q-switched operation explains why more than just one or two rotational lines oscillate in a particular vibrational band.

Fig. 3 illustrates the effect of 400 Torr of water vapor on the spectral output of the Q-switched laser. Only the net gain of the device can be changed by the water vapor since only loss is being added. The peak of the gain profile for the vibrational bands is seen to shift towards the lower bands since less loss is being added to these bands. Even the slight additional loss for the 3-2 band is too much to sustain oscillation on these lines. The effect

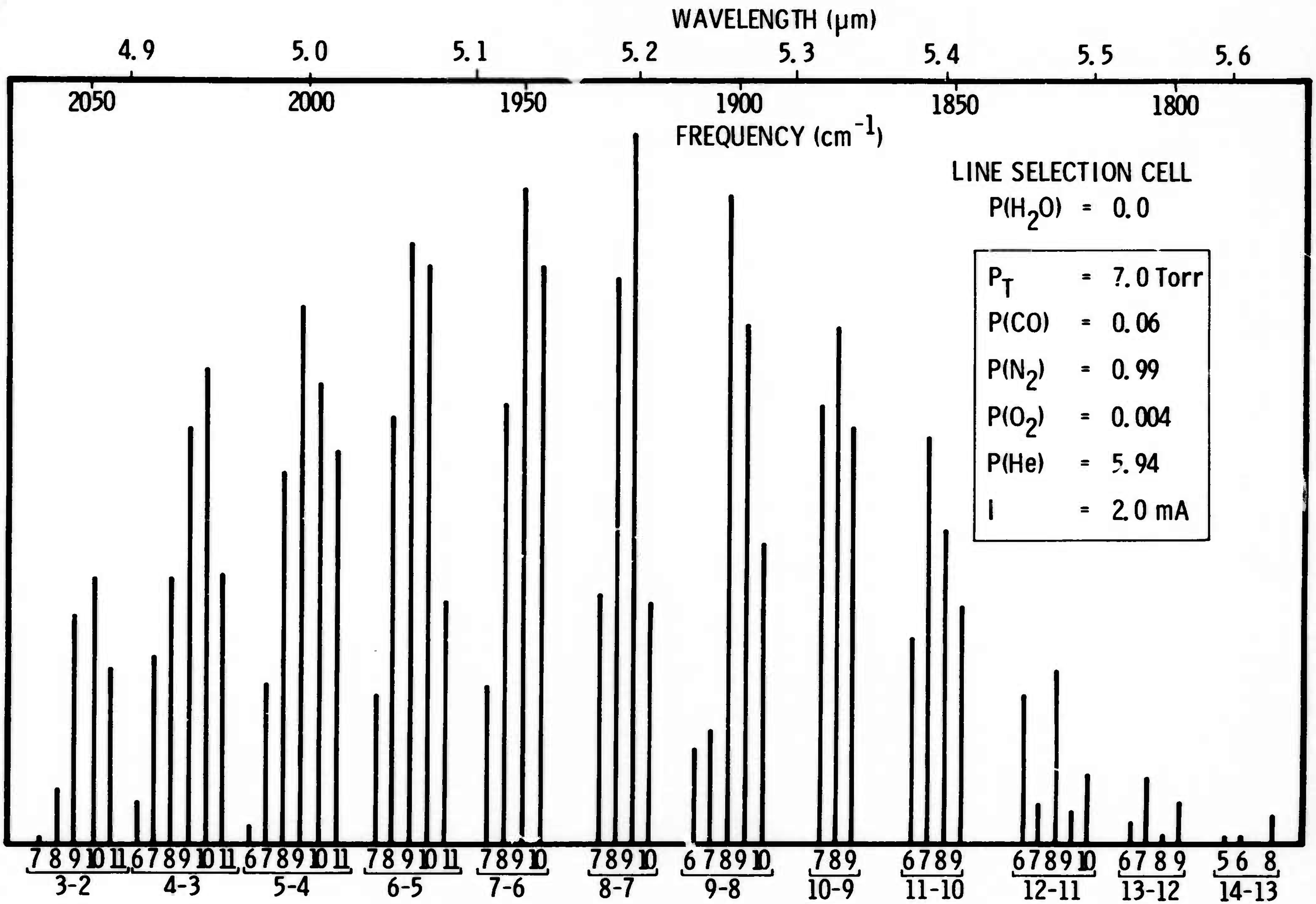

Fig. 2. Output Spectra of Low Pressure Longitudinal Discharge, Repetitively Q-Switched (40 pps) CO Laser.

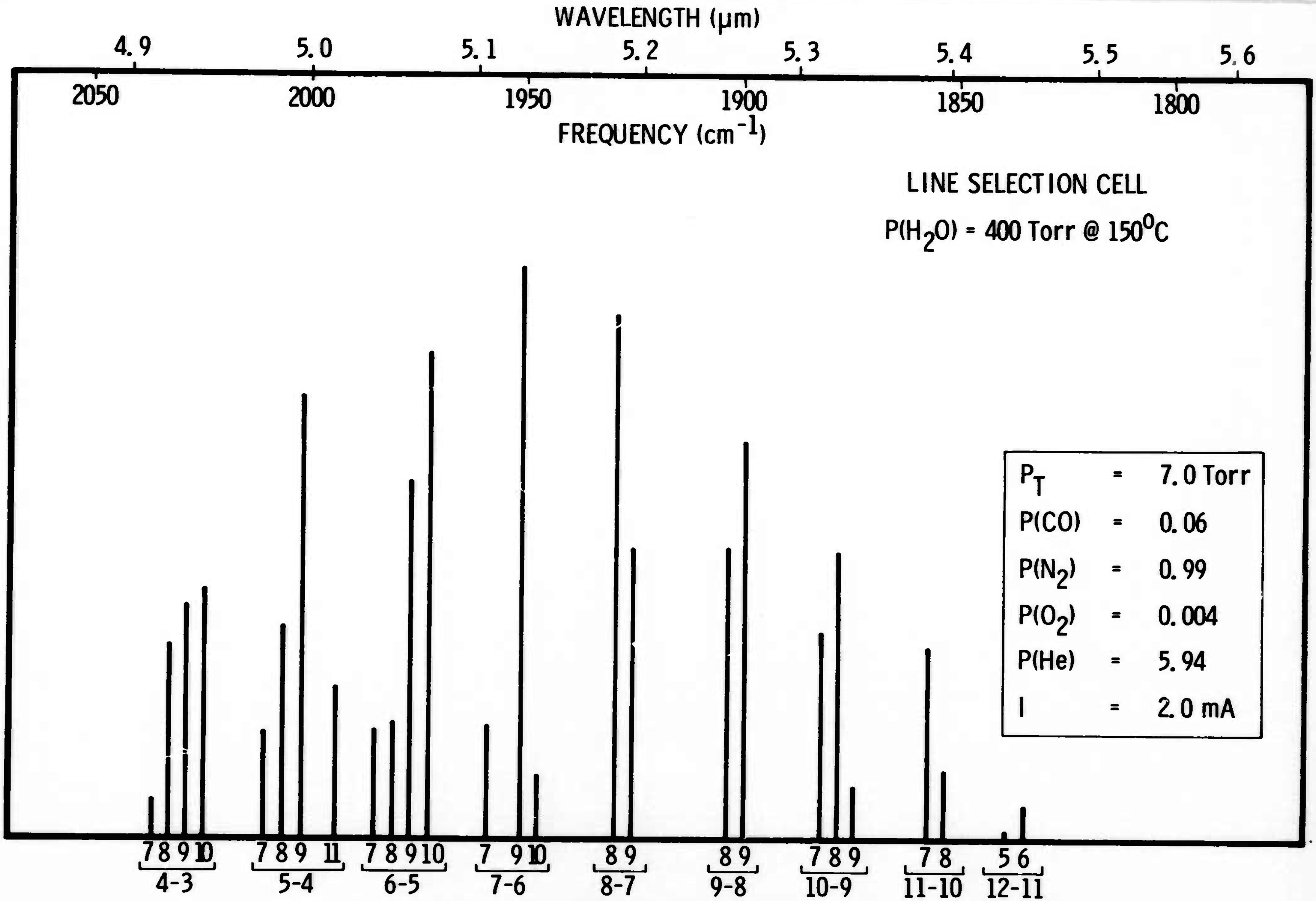

Fig. 3. Output Spectra of Low Pressure Longitudinal Discharge, Repetitively Q-Switched (40 pps) CO Laser.

of the absorption loss on the other bands is dramatic; many of the rotational lines have been eliminated, demonstrating that different losses have been added for each line. Fig. 4 shows the results with 700 Torr of water vapor, where oscillation has been limited to only the rotational lines with lowest loss in each band. These lines also have the highest predicted atmospheric transmittance for each band. For example, in Fig. 2 it is observed that with no water vapor in the cell the 6-5 vibrational band lines present were P(7) to P(11). These lines have predicted atmospheric attenuation e-folding distances for the Midlatitude Winter Model at sea level of 8.77, 6.67, 13.51, 14.49 and 1.75 km respectively.[2] From Fig. 4, representing 700 Torr of water vapor in the cell, only the 13.51 km and 14.49 km lines remain, i.e. 6-5 P(9) and P(10). These results are very encouraging considering the slow rotational cross relaxation and high gain Q-switching effects.

Fig. 5 illustrates the spectral output for cw operation of the laser. The gain is not sufficient to provide for oscillation of the 3-2 lines in the configuration of this experiment. Rotational cross relaxation processes are a function of the pressure of the laser and for the low operating pressures of this device the rotational cross relaxational times are slow. Therefore even though equilibration of the kinetic processes can occur because of the continuous nature of the oscillation, more than one rotational line is evident for several of the vibrational bands. The percentage value shown above each line gives its fraction of the total output power. These numbers are obtained utilizing the integrated output function of the chart recorder. The parenthetical value above each line is its predicted atmospheric attentuation e-folding distance for the Midlatitude Winter Model at sea level.[2] Fig. 6 shows the output spectra resulting from the addition of the water vapor cell containing 400 Torr of water. Oscillation is tending to shift from the rotational lines of Fig. 5 to those lines having the highest atmospheric

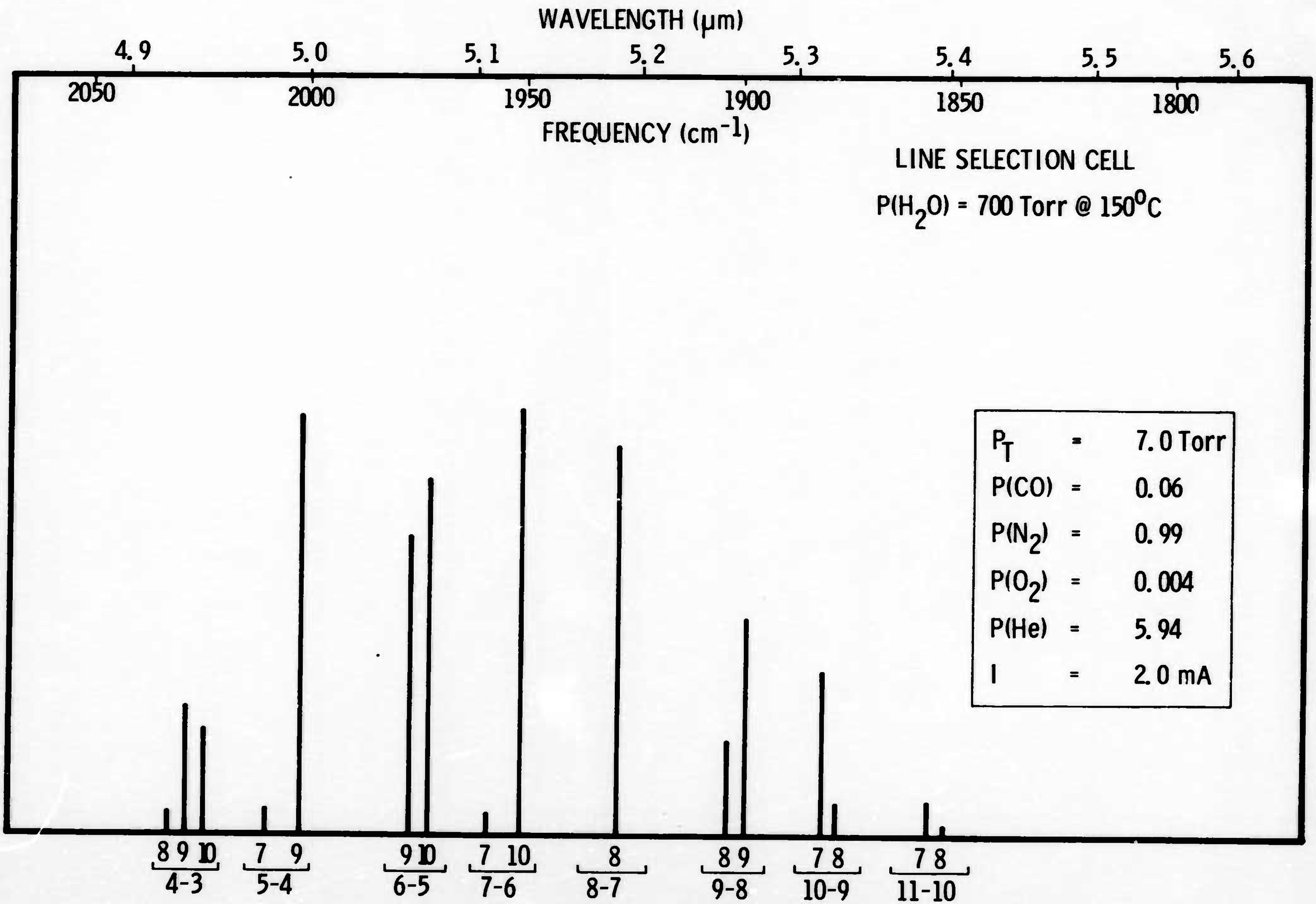

Fig. 4. Output Spectra of Low Pressure Longitudinal Discharge, Repetitively Q-Switched (40 pps) CO Laser.

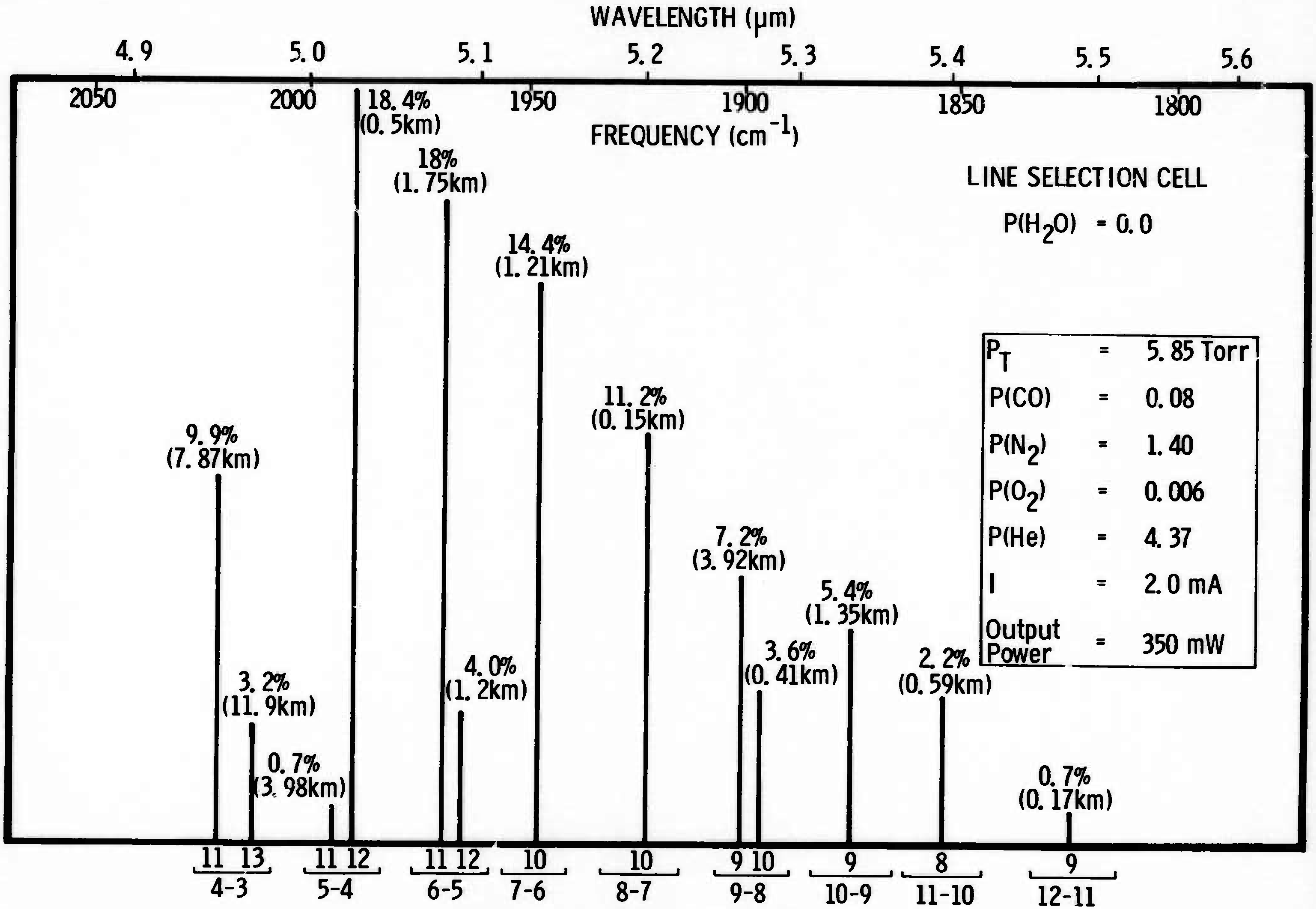

Fig. 5. Output Spectra of Low Pressure Longitudinal Discharge cw CO Laser.

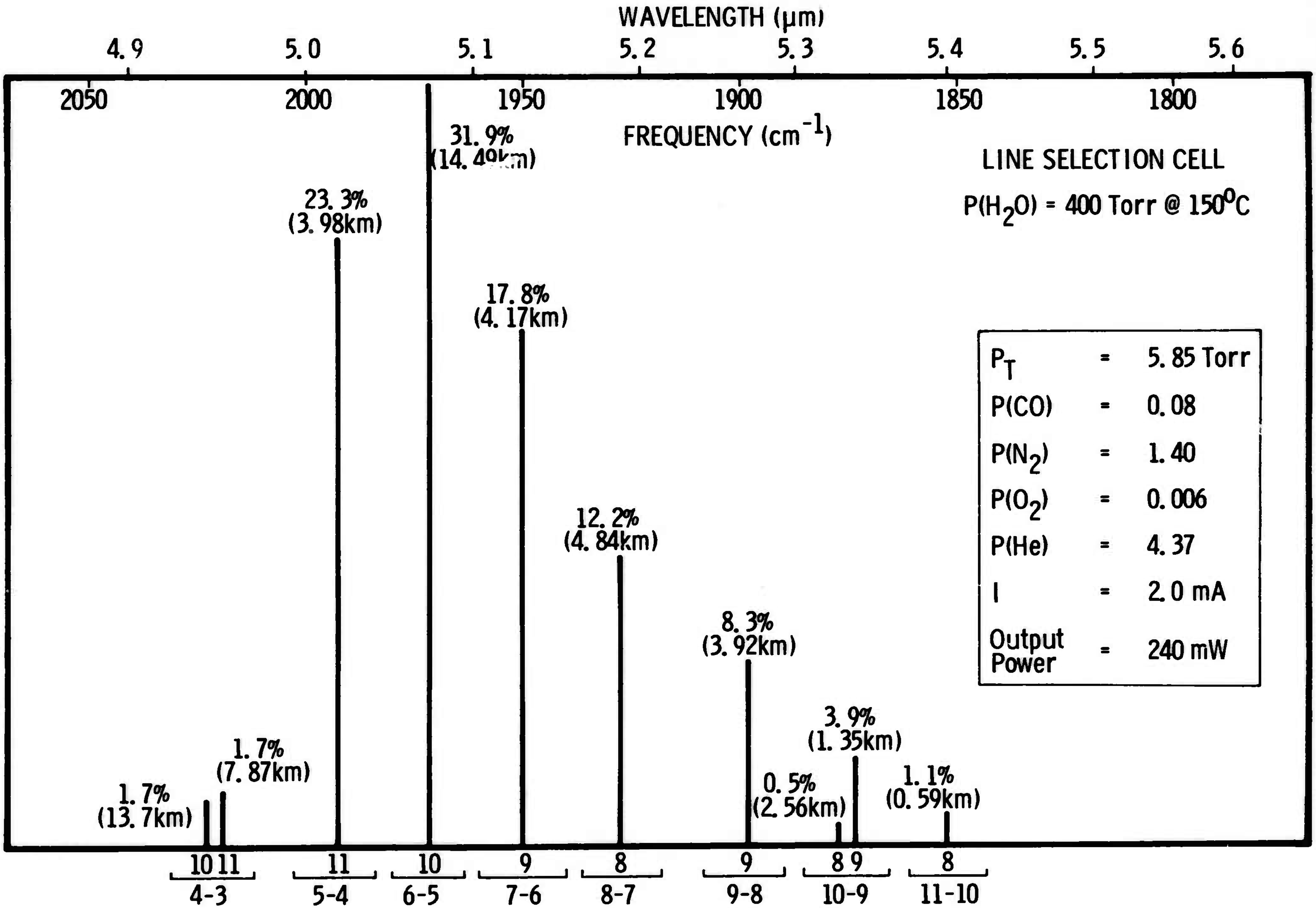

Fig. 6. Output Spectra of Low Pressure Longitudinal Discharge cw CO Laser.

transmittance. The tendency is also towards one rotational line per vibrational band. Fig. 7 shows the output spectra with 700 Torr of water vapor. Only one rotational line is oscillating in each vibrational band. Note that 63% of the output power is contained in the high atmospheric transmittance lines of the 6-5 band and lower. Not only has the water vapor initiated rotational line selection, it has also provided for vibrational line selection by prohibiting oscillation on the high vibrational bands. The output power dropped from 350 mW without water vapor in the cell to 150 mW with 700 Torr of water vapor. If the gain of the laser could be peaked in the lower vibrational bands, the efficiency using line selection would be greatly improved.

B. High Pressure E-Beam Device

The configuration for experimental spectral line selection of an electron beam stabilized pulsed CO laser is shown in Fig. 8. The water vapor cell used was the same device as discussed in Section IIA. Since the cell has a clear aperture of 2.5 cm and the laser has a clear aperture of 4.8 cm, only a small section of the active medium could be utilized due to vignetting. The output energy was focused into the spectrometer (Optical Engineering CO Spectrum Analyzer). The fluorescent screen of the spectrometer and resulting spectra of the laser pulse was recorded photographically.

The results of these experiments are shown in Fig. 9. The vertical lines illustrate only spectral location and not intensity. The value next to each line represents the predicted atmospheric e-folding distance. The pertinent parameters of the laser are listed in the figure. The output consists of a single pulse with a temporal width of approximately 100 μsec. The spectral results for 700 Torr of water vapor are illustrated in the bottom figure. Only one rotational line is present for each vibrational band. These lines

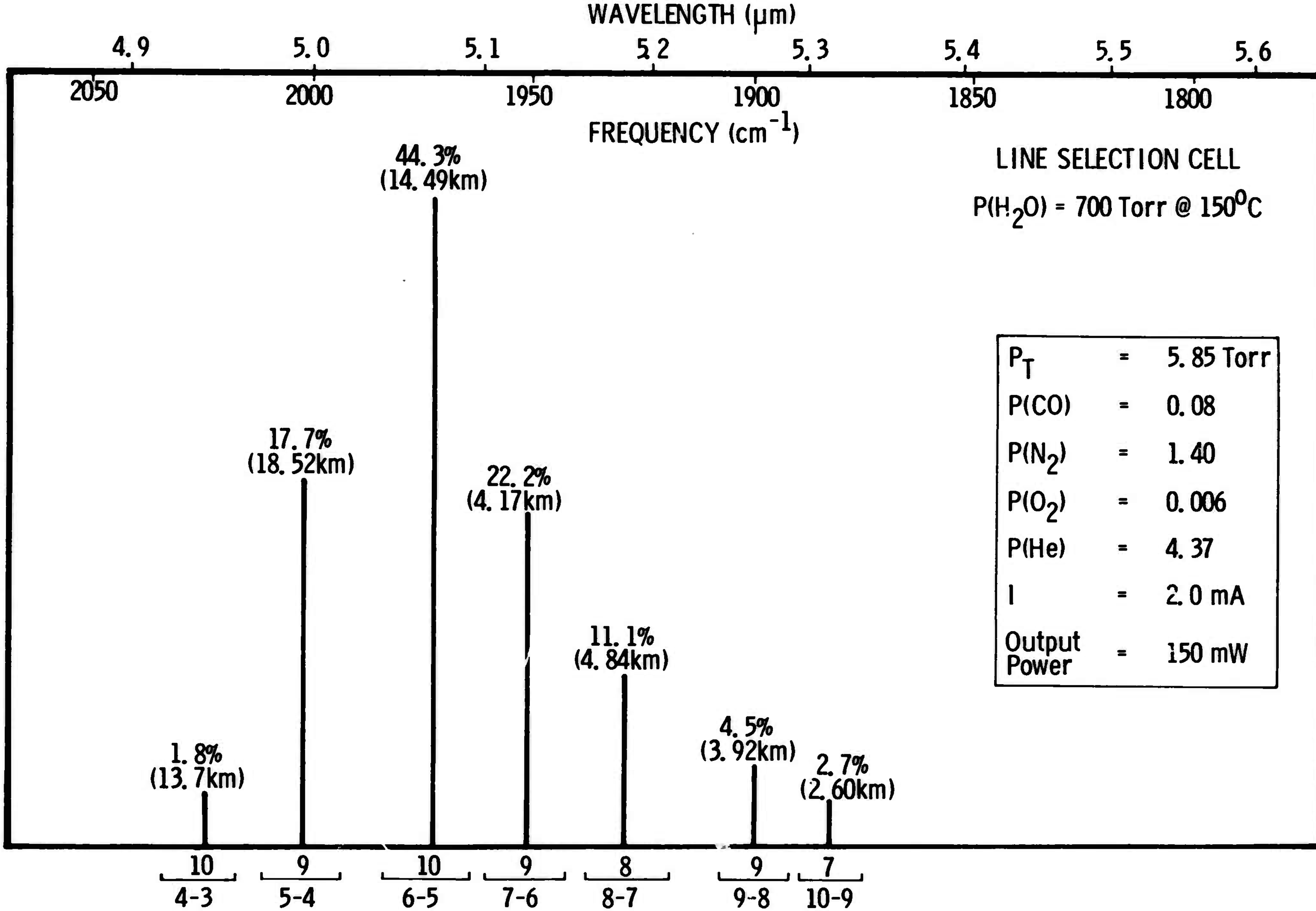

Fig. 7. Output Spectra of Low Pressure Longitudinal Discharge cw CO Laser.

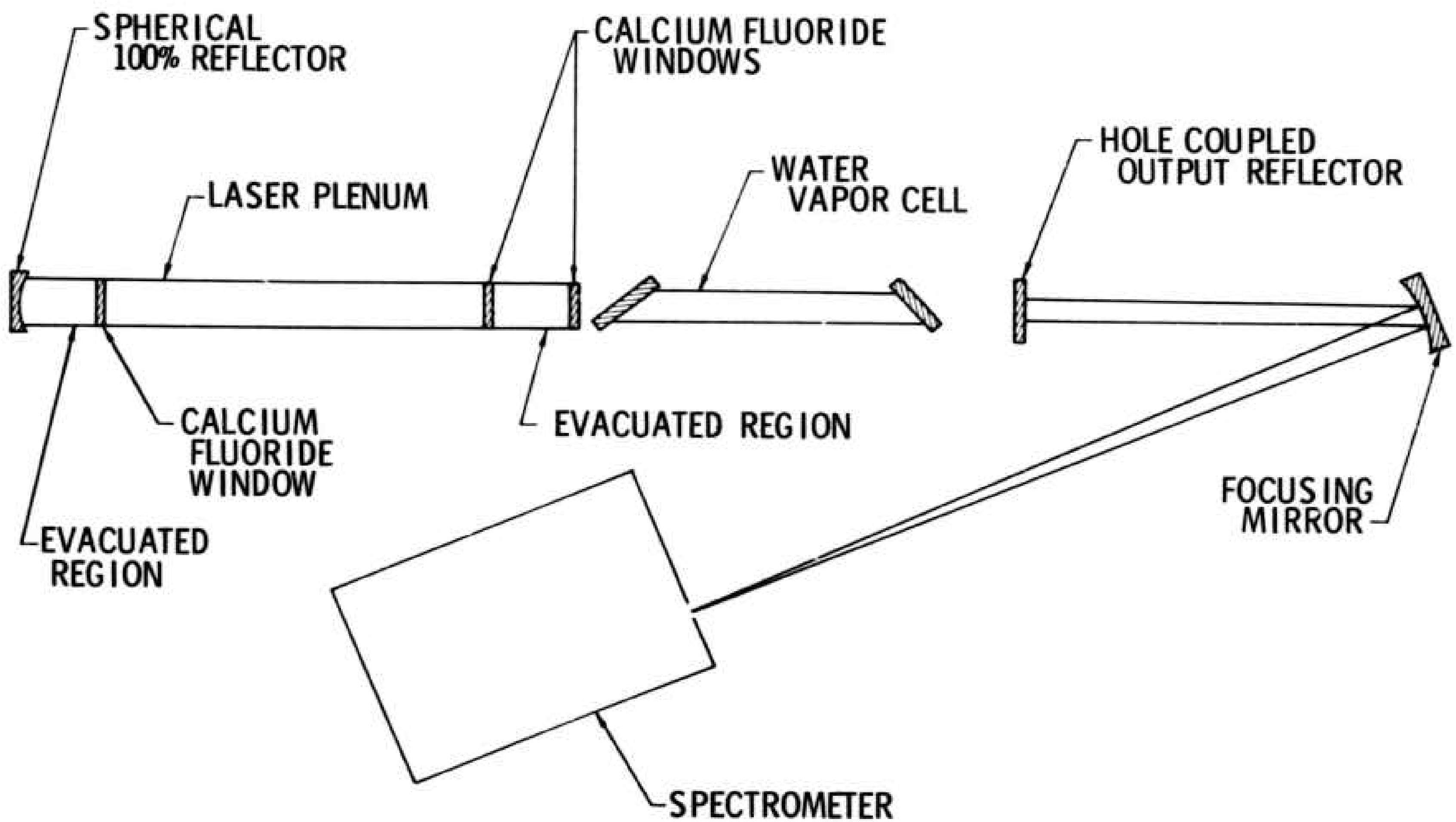

Fig. 8. Spectral Line Selection Configuration for E-Beam CO Laser.

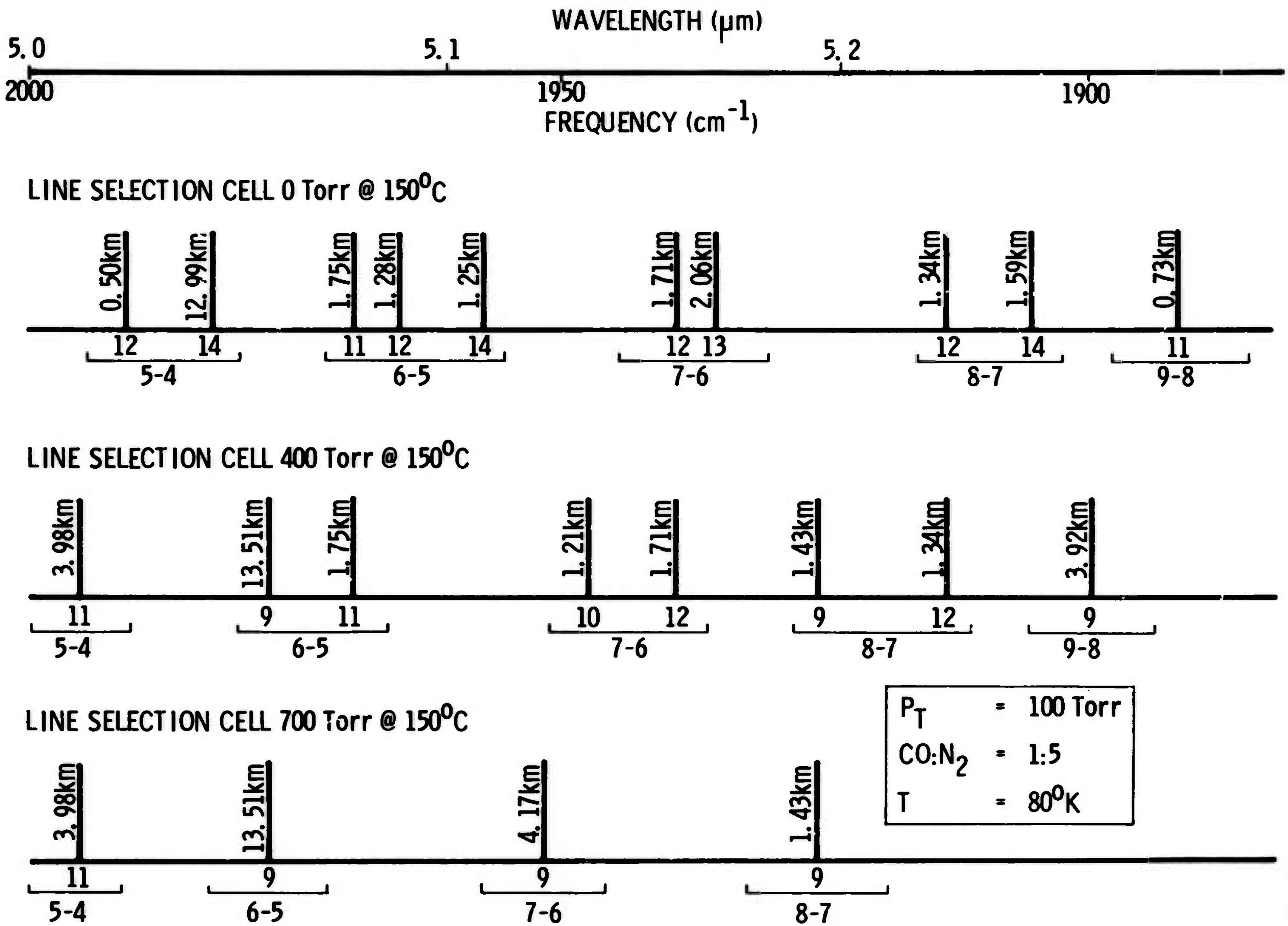

Fig. 9. Line Selection Performance of E-Beam CO Laser.

have higher predicted atmospheric transmittance than the lines with no line selection. For example, with no water vapor in the cell none of the lines oscillating in the 6-5 band have predicted high atmospheric transmittance, yet with 700 Torr of water vapor the only line present in the V-band has a predicted e-folding distance of 13.51 km. In addition to the rotational line selection a certain amount of vibrational line selection has occurred as evidenced by elimination of the 9-8 transitions.

The configuration of this particular E-beam laser does not have the optimum cross sectional aspect ratio to provide the required electrical pumping to limit oscillation to only the lower vibrational bands. Kinetic modeling investigations predict that as the level of electrical pumping is increased relative to pumping, the output spectrum shifts toward the lower vibrational bands.[12,13] As discussed previously, these low vibrational bands contain the rotational lines having the highest predicted atmospheric transmission. With the proper pumping configuration, the efficiency of the laser is predicted to be affected minimally by the line selection device.

III. SUMMARY

The results of this investigation indicate that a intracavity water vapor cell can be used for spectral line selection of the rotational transitions of carbon monoxide lasers. The technique was verified for low pressure longitudinal discharge lasers operating in the cw or repetitively Q-switched modes. In addition the technique was demonstrated with an electron beam stabilized pulsed CO laser. With the appropriate water vapor content in the cell, laser action tends to be limited to only the rotational transition in a particular vibration band corresponding to a wavelength predicted to have high atmospheric transmittance.

As anticipated, the use of the water vapor cell to perform vibrational band selection adversely affects the normal high efficiency of the CO laser. If the operating parameters of the laser were adjusted so as to provide gain for only the lower vibrational bands (6-5 → 1-0), the water vapor cell technique would provide for rotational line selection without seriously degrading the overall laser efficiency. This should be especially true for the e-beam devices where the operating pressure is such that the rotational cross-relaxation time is sufficiently fast to allow extraction of essentially all of the stored vibrational energy on a single rotational line per V-band. Therefore, efficient laser action will result on only those spectral lines having high atmospheric transmittance.

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